Design and Comparison of 2x2 Array Antenna using Integrated and Conventional Feeding Network

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***Abstract*— Integrated feed comprises of microstrip and probe feed. The integrated feed technique applied to 2x2 array of patch antenna gives superior result compared to array of same antenna using conventional feed. An array of 2x2 patch antenna when applied with integrated feed gives an efficiency of 58%. Whereas, array of same antenna using conventional feed has an efficiency of 13.2%.**

***Index Terms*— Antenna array, integrated feed, power divider, microstrip feed, efficiency, quarter wave transformer.**

I. INTRODUCTION

Antennas designed for any application requires to be efficient enough to radiate out maximum power given to it.

The radiation efficiency of antenna depends on radiation resistance of the antenna [1]. The efficiency of a perfectly matched antenna is given as:

$$\eta = \frac{R_r}{R_r + R_l}$$

Where η is antenna efficiency

Rr is radiation resistance of the antenna

R_l is loss resistance of antenna.

The radiated power from a single antenna is radiated out in large angle and power is distributed over the entire region falling within that angle therefore to confine power into a small region and transmit that power to a longer distance antenna array is used. Array of antenna has been playing very important role in long distance communication such as satellite communication, space exploration, medical and security system. Array can be designed using any fundamental antenna. Micro Strip antennas (MSA) are mainly preferred to make array of antenna at higher frequency due to small size and ease of manufacturing. The advantages of array antenna are narrow beam of radiation, higher gain but at the cost of larger overall antenna size. Gain is one of the most common measurements stated on antenna specification sheets. In a transmitting antenna, the gain describes how well the antenna converts input power into radio waves headed in a specified direction. It acts as key performance number and combines the directivity and electrical efficiency of an antenna. Higher the gain of the antenna is, the more focused beam is obtained. An antenna array is used to increase overall gain, gage the direction of arrival of incoming signals, and to maximize the Signal to Interference Noise Ratio (SINR).

Design of array consists of many other components other than the fundamental antenna. Array of antenna works on two fundamental factors separation distance between the antennas and phase difference between them. These parameters are chosen completely based on the kind of radiation pattern needed from the designed array [1].

II. RELATED WORK

It is claimed that an array of 1x4 antenna designed at 6 GHz has high gain of 14 dB and efficiency of 97%. But the aperture coupling technique leads to a high back radiation which is not recommended for a directional antenna [2]. Array of antenna designed at 2.4 GHz under different configurations like 2x1, 4x1, 8x1 and 8x8 offers different gain and maximum gain attained for 4x1 array is 8.15 db. But such high gain is attainable only if antenna efficiency is high. There is no explanation of efficiency given by the authors, [3]. Wireless antenna array designed at 2.4 GHz using 3x3 and 2x4 array gives a pencil line sharp beam which is applicable for portable devices. Array always leads to a sharp pencil like beam but the distance to which the wave reaches depends on gain of the antenna and the efficiency of the designed array is not included in the literature [4].

Efficiency of array antenna can be improved using shorting pins in the antenna. The proposed antenna element is extended to 2 × 2 and 4 × 4 arrays, resulting in aperture efficiencies of 74.2% and 80.5%, respectively. For the 2 × 2 array, maximum measured gains of 19.9 dBi in the zx-plane and 18.8 dBi in the zy-plane are observed [5]. Though the shorting pin technique improves the efficiency of array antenna but there is no standard way to decide location of these pin and design of such antenna becomes difficult.

All the works covered in the literatures are either dedicated to aperture coupled microstrip antenna or probe feed microstrip antenna. The aperture coupled antenna offers better efficiency of around 97% but suffers with back radiation. Probe feed antenna does not have such issue but gives greater efficiency only for higher substrate thickness. A microstrip line is a transmission line and can be divided into number of paths to feed multiple antennas. A probe feeding technique is a single point contact and cannot be divided into multiple paths therefore despite of being an efficient technique than microstrip line, it is not suitable to feed array antenna. It is suitable for a single antenna. In this paper two different arrays are designed and compared. First, a conventional 2x2 array antenna is designed using conventions microstrip power divider. The same array is fed with a newly proposed feed which is combination of probe and microstrip power divider feed.

III. METHODOLOGY

An array of 2x2 antenna comprises of 4 basic patch antennas and arranged as shown in following figure, Figure 1. The array is designed on FR-4 substrate with thickness of 1.6 mm and is simulated using CST studio software. Each patch of array is 36x36 mm^2. Individual patch resonates at 2.4 GHz and impedance at this frequency reaches to 55 Ω. In order to make array of this antenna, three more antennas are paced at a distance of 62.5 mm which is λo/2. Since the antenna array is fed with a single feed, a power divider is needed to feed all antennas with zero phase difference. Zero phase difference can be achieved by having same length of feed line. Figure 1 shows the impedance of each quarter wave line involved in feeding the patches. The main feed of array is connected with 100 Ω loads coming from lower and upper array of 1x2 antennas. This line of 100 Ω since divides in parallel to feed the two sections, its parallel combination turns into 50 Ω and thus works as matched load to main feed of 50 Ω. The two antennas each with almost 50 Ω is fed with a quarter wave transformer of 70.7 Ω. This quarter wave transformer transforms antenna impedance from 50 Ω to 100 Ω. The array of 1x2 antenna with quarter wave lines comes in parallel and the overall impedance of each array offers impedance of 50 Ω. This impedance of 100 Ω from lower and upper array of 1x2 antenna appear as a load of 50 Ω to main feed of 50 Ω. This task is achieved with the help of another quarter wave transformer to convert these 50 Ω into 100 Ω. Finally, two 100 Ω load, each from upper and lower array appears in parallel to the main feed. This parallel combination of two arrays appears as 50 Ω to the main line and matching is achieved between 2x2 array antenna and main feed line. Table 1 shows the performance of array antenna. Table 1 shows that the antenna directivity is very high but the efficiency of the antenna is very poor and therefore the gain drops to 2.95 dB. The drop is efficiency is due to thin substrate involved in the design of array. A thick substrate can improve the efficiency of the array antenna but designing power divider with such thick substrate may lead to unwanted radiation and practical issues. Therefore, an integrated feed can be used.

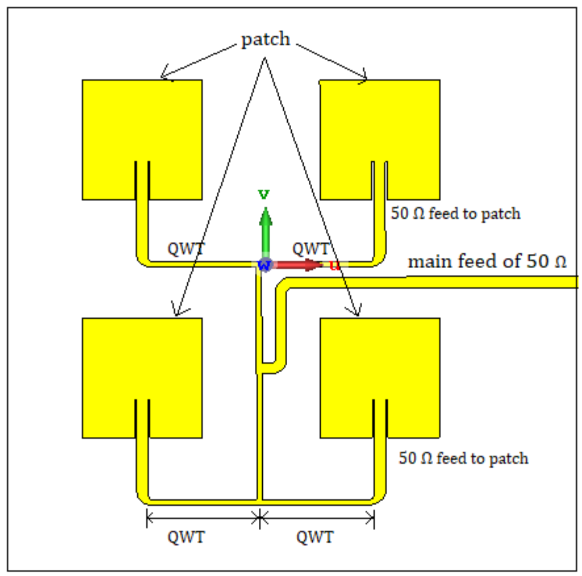
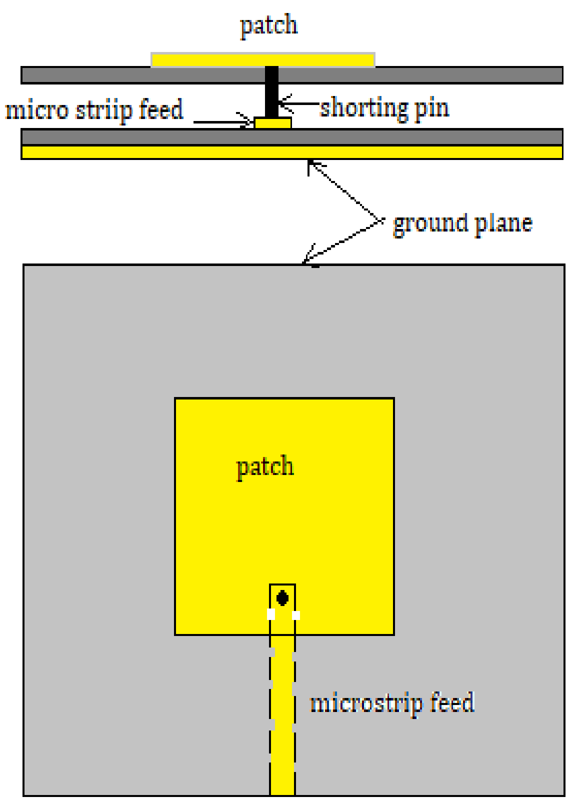


Figure 1: Array of 2x2 antenna with conventional feed.

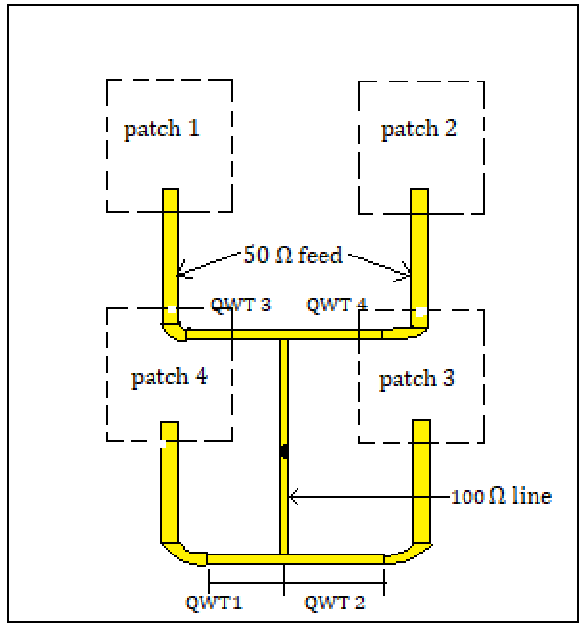
Table I: Performance of 2x2 antenna array

Antenna Case	Directivity (dB)	Efficiency (%)	Gain (dB)
2x2 array	11.7	13.2	2.95

Figure 2 shows the arrangement of array while using Integrated feed. An integrated feed is combination of probe feed and microstrip feed. The probe feed is used to maintain a good gap between patch and ground plane, this helps in improving the antenna efficiency. The integrated feed requires two substrate one for accommodating patches and other to design microstrip power divider using quarter wave transformer. The power divider is connected to patch available on the other substrate using shoring pins as shown in Figure 2. A single patch is created on top of a substrate and is fed with a shorting pin connected with microstrip line of 1.5 mm width and 44 mm length as shown in Figure 2(a). Complete structure of array antenna with integrated feed is shown in Figure 2(b). There are four quarter wave transformers and each one is used to transform the impedance of antenna to make it compatible with main feed of 100 Ω, which is fed with a 50 Ω probe feed. The difference in main feed of earlier array and this array is that the main feed in the earlier case is a microstrip line whereas in integrated feed it is a combination of probe feed and microstrip feed. The role of the quarter wave transformer is similar to the earlier case of 2x2 array. The main feed of 100 Ω is 1.4 mm wide and 62 mm long to connect the two pairs of antennas above and below as shown in fig. 2(b).



(a)



(b)

Figure 2: Single antenna (a) array antenna (b) using Integrated feed

Since each quarter wave transformer is transforming 50 Ω into 200 Ω the characteristic impedance of each line is 100 Ω only and length of each transformer is 31.5 mm to satisfy the criteria of being λo/4. In order to meet impedance of 100 Ω, each quarter wave transformer is 1.4 mm wide. Substrate dimension is 200 x 200 mm^2. The gap between substrates is 5 mm and each substrate is of 1.6 mm thick therefore the gap between patch and ground plane is 8.2 mm.

IV. EXPERIMENTAL RESULTS

Simulated result of the antenna array shown in Fig. 3 confirms that it is very well tuned at 2.4 GH with return loss of -16.77 dB. Efficiency of array is 58% and gain of the antenna is 8.85 dBi with beam width of the antenna is 46.6^0. Though the gain of the array is larger than the conventional array but the efficiency of the antenna is only 58%, as shown in Fig. 4.

The radiation from the antenna is highly directive and beamwidth of the antenna array is 46.6^0, as shown in Fig. 5. Table II shows the comparison between the two arrays. It can be observed that the proposed antenna array feed with integrated feed outperforms the conventional array antenna.

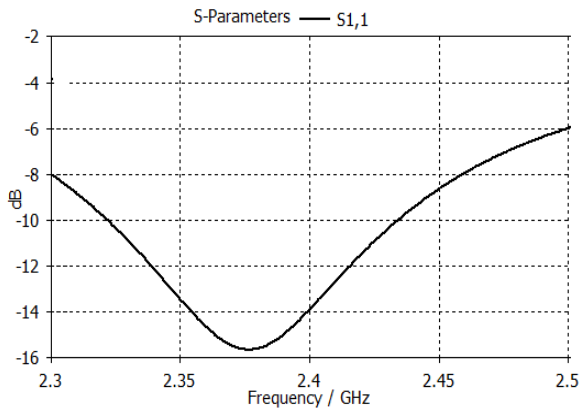


Figure 3: Frequency V/S reflection coefficient.

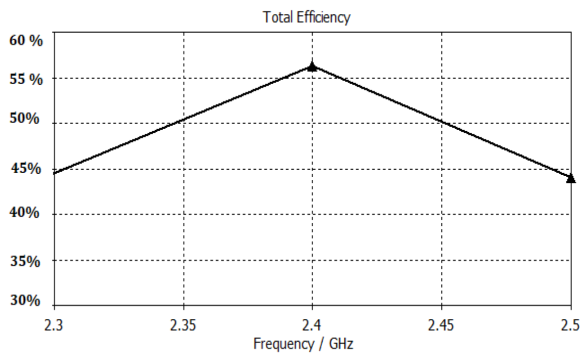


Figure 4: Frequency v/s antenna efficiency

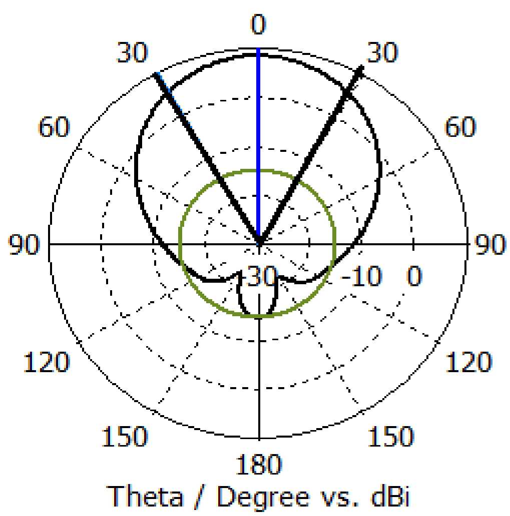


Figure 5: Radiation pattern of antenna at 2.4 GHz

Table II. Performance analysis of patch array fed with integrated feed.

Sr. No.	Antenna Parameters	Array with Integrated Feed	Array with Microstrip Feed
1	Return loss	-16.77 dB	-20 dB
2	Efficiency	58%	13.2%
3	Directivity	11.2 dBi	11.7 dBi
4	Gain	8.85 dBi	2.95 dBi
5	Beam width	46.6^0	45.8^0
6	Patch size	36 mm	31.5 mm

V. CONCLUSION

Integrated feed provides a better approach to feed antenna array with improved efficiency which leads to improvement in antenna gain. The integrated feed technique applied to 2x2 array of patch antenna gives improved result compared to array of same antenna using conventional feed. Integrated feed comprises of microstrip and probe feed. The drop in efficiency of integrated fed patch array can be attributed to the feed which is 1:4 power divider and lies under the patches involved in radiation. Therefore, designing of power divider in a different way may lead to improvement.

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